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Phosphoric Acid Fuel Cell Technology Status

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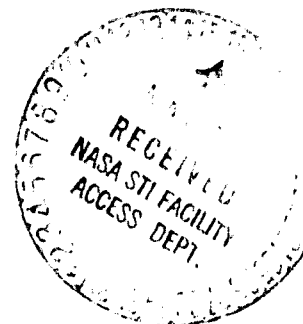
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Prepared for
Fuel Cells: Technology Status and Applications
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BACKGROUND

In its most basic form a fuel cell is a static electrochemical device that converts continuously fed fuel and oxidant to water, heat, and most importantly DC electric power. A fuel cell, like a battery, is composed of two electrodes (an anode and a cathode) where the reactions take place separated by a reservoir of electrolyte that allows ions to flow between the two electrodes. The circuit is completed by connecting an external load across the two electrodes. What differentiates a fuel cell from a battery is that in a fuel cell the reactants are continuously fed to the electrodes whose function is to provide a surface upon which the reactions occur. In a battery the electrodes are chemically changed as the reactions occur and must be restored (a secondary battery) or are simply used up (a primary battery).

The various types of fuel cells are distinguished by their electrolyte, as shown in Fig. 1, which plots cell voltage, a measure of efficiency, against cell operating temperature for all fuel cell types that are presently under development for commercial applications. A perfectly efficient cell is shown for comparison. Even though phosphoric acid cells have the lowest efficiency of the fuel cell types shown, they are the subject of much of the current development work. This can be explained by their having the best combination of proven cell life, tolerance to impurities in the fuel and oxidant, low cost, and proven manufacturability.

On a national basis several public and quasi-public agencies support three potential fuel cell manufacturers for multikilowatt and multimegawatt systems, and several smaller corporations for basic research. Multikilowatt systems (particularly on-site integrated energy systems that use both the electricity and waste heat from the fuel cell) are appropriate for residential, commercial and small industrial applications. Currently United Technologies Corporation (UTC) and Engelhard Industries are developing these systems. Multimegawatt systems are appropriate for electric utility and industrial cogeneration. Westinghouse Electric Corporation and UTC are currently developing systems for these applications.

In this paper a review of the status of the major phosphoric acid fuel cell development efforts is presented. In both the electric utility and on-site applications reducing cost and increasing reliability are the technology drivers at this time. The longstanding barrier to the attainment of these goals, which manifests itself in a number of ways, is materials. The differences in approach among the three major participants and their unique technological features, including electrodes, matrices, intercell cooling, bipolar/separator plates, electrolyte management, fuel selection and system design philosophy are discussed for each manufacturer and system.

UTC ON-SITE SYSTEM

In the late 1960's a group of gas utilities became interested in the development of a fuel cell power plant for residential and commercial applications. They formed the Team to Advance Gas Energy Transformation (TARGET) which, together with UTC, developed a natural gas-fueled 12.5 kw power plant. These power plants were field tested at 35 sites in the U.S. and abroad, and accumulated a total of 205,000 hours. In addition to advancing fuel cell technology the TARGET program investigated the market opportunities and requirements, the legal and regulatory issues, and the requirements these placed on the fuel cell power plant.

By the early 1970's the TARGET experience indicated that some design changes and technology advances were required. A massive commercial introduction was assumed; this resulted in specifying a 40 kw power plant as the first in a catalogue consisting of many sizes of power plants. It was designed to use the whole range of pipeline quality gas, including propane/air peak shave and high sulfur gas, and to produce grid quality power in a stand-alone, load following mode. This represents the current state-of-the-art at UTC for unpressurized power plants and is the unit to be used in the 40 kw field test.

A simplified schematic of the 40 kw power plant is shown in Fig. 2. Pipeline gas enters the power plant and first goes to the fuel clean-up system where oxygen, sulfur, and halogens are removed and unsaturated hydrocarbons are broken down. Steam is then added to the cleaned fuel and it is reacted in a reformer to form a hydrogen, carbon dioxide and carbon monoxide rich stream. This stream is sent to a shift converter to react the carbon monoxide and steam to further increase the hydrogen yield. This hydrogen-rich stream is sent to the anode, where most (normally 80%) of the hydrogen is consumed. The rest is sent back to the reformer, where it is burned to provide heat to the endothermic reforming reaction. Air is ducted to the reformer burner and to the fuel cell cathode. At the cathode, oxygen is consumed and the product water is produced. The water-rich cathode exhaust stream and the reformer burner exhaust, which also contains water vapor, are combined and passed through a series of condensers. The water recovered in the condensers is used as makeup for the coolant systems. The fuel cell stack is cooled by a circulating water system. Water near the boiling point enters and is partially vaporized as it passes through the stack. Steam is taken off in a separator and used in the reformer. Make-up water comes from the condenser, so the power plant is water self-sufficient.

Cell Stack

The heart of any fuel cell power plant is the stack of individual cells that produce DC power. It is also where one of the major technology improvements occurred for the 40 kw power plant. The advanced cell structure concept, commonly called the integral ribbed substrate, is UTC's approach to lowering cell stack cost and, simultaneously, increasing electrolyte storage capacity over their older compression molded configuration. The ribbed substrate, shown in Fig. 3, consists of a porous grooved (ribbed) material that is composed of graphite fibers and a binder. It is porous to allow for gas

diffusion from the groove, which carries the bulk reactant flow, to the unribbed side where the electrode is located. The pores are also used to store sufficient electrolyte for the fuel cell operating life. The steps in manufacturing and assembling a fuel cell stack are as follows:

- (1) The substrate is continuously formed from a mixture of graphite fibers and resin binder. Extra fibers and resin are deposited at the edges to form a dense seal area. The substrate is compressed and heated sufficiently to set the resin, then individual substrates are cut off the sheet.
- (2) The substrate is heat-treated in an inert atmosphere to decompose the resin, thus making the substrate more corrosion resistant and porous.
- (3) The electrocatalyst and electrolyte matrix are applied to one face of the substrate in successive operations.
- (4) The grooves are cut in the substrate on the side opposite the electrode and matrix. This completes the manufacture of a half cell, either anode or cathode.
- (5) A single cell is made by stacking two half cells together with matrix sides facing and ribs perpendicular. The ribs are perpendicular so that the fuel and air can be in cross flow. A fuel cell stack is made by stacking single cells with a gas impermeable separator between each single cell.

Current R&D activities in the stack area are to find lower cost materials, develop a manufacturing process that continuously molds the grooves in the unheat-treated substrate (thus eliminate step 4 above), and develop a dual porosity substrate that will hold more electrolyte without increasing gas diffusion resistance.

Stack Cooling

A fuel cell stack must be cooled to remove the excess heat of reaction. UTC uses two phase water as the coolant and employs intercell coolers placed between each set of five cells in the stack. A cooler consists of an array of thin wall copper tubing imbedded in a conforming holder which is similar in composition to the ribbed substrate. The copper tubes must be coated with a thin protective film of PFA (a Teflon-type material) to prevent corrosion from the phosphoric acid that migrates into the cooler.

Two-phase water is a good choice for a cooling medium for several reasons. The temperature profile across the stack is very uniform since the cooling is provided by constant temperature vaporization of the coolant, rather than by a temperature increase of the coolant. Since both fuel cell performance and all life-limiting processes are directly proportional to temperature, a flat temperature profile will give the best compromise between highest performance and longest life. The other advantage of two-phase water is that the steam can be used directly to raise the pressure of the fuel (via an injector) and then as a reactant in the steam reformer. Other cooling schemes require a separate steam boiler.

The chief disadvantage of this type of intercell cooler is its relatively high manufactured cost. This is compounded by the need for additional coolers to provide the extra heat transfer area needed because of the low conductivity of the PFA coating. The probability of cooler failure due to a breach of the PFA film and subsequent corrosion of the copper has not yet been established. Considerable test time has been accumulated on two partial stacks (24 cells) and a full stack (270 cells) with only one tube failure. This failure was traced to mechanical damage to the PFA coating. As a result of the failure the coating thickness has been increased and procedures have been established to avoid handling damage.

Future cooler R&D will concentrate on improving the integrity of the PFA coating or preferably eliminating the PFA entirely by either totally encapsulating the cooler to keep acid away from the copper or finding an acceptable coating with better heat transfer than PFA.

40 kW Field Test Power Plant

The UTC OS/IES 40 kW system has a number of unique characteristics. It is designed to handle not only natural gas but also peak-shaved gases which contain typically oxygen, propane and propylene. The power plant is designed to deliver electrical power and hot water as the heat recovery fluid. Utilization of the heat is to be the responsibility of the user.

The Field Test will be carried out in two stages to permit incorporation of technology advances (generated by parallel technology development efforts) into the power plants being tested. However, there will be no break (of greater than a few months) in the manufacturing effort as a result of this staging.

Prior to each Field Test stage, the plan calls for final selections of the technology to be incorporated as well as the necessary power plant design modification to incorporate the changes. For the Stage I Field Test the technology expected to be ready includes the technology currently under development under the extension to the Preprototype E&D work. For the Stage II Field Test, additional technology stemming from the planned Technology Development work is expected to be ready for incorporation.

A substantial number of power plants is to be tested in each stage of the Field Test by a large group of gas utilities, combined utilities, and a few electric utilities. The precise number in each stage will be determined as soon as budget and other considerations are settled.

The power plants will be installed over a range of attractive early entry applications and geographical areas to acquire data covering representative variations in electrical and thermal load use patterns, energy system configurations, climate, competitive service economics, and institutional, legal and regulatory matters. The installations are to include a variety of multi-unit residential, commercial, and light industrial applications. The operating goal for each of the power plants is a minimum of 8000 hours.

UTC ELECTRIC UTILITY PROGRAM

This program is a continuation of the Fuel Cell Electric Utility Program initiated in 1971 by EPRI, a group of nine electric utilities (the FCG-1 group), and UTC to develop fuel cell power plants for terrestrial power generation. Two major milestones have been achieved thus far: (1) a 1 MW "breadboard" power plant configuration was tested at UTC in 1977, and (2) a 4.8 MW "preprototype" power plant has been fabricated and installed for field test at a Consolidated Edison, New York City site. The goal of the present program is to advance the power plant technology to the "prototype" level of development. The plan to accomplish this is comprised of three elements: (1) Prototype Power Plant Technology Development and Verification, (2) Prototype Power Plant Engineering and Design, and (3) Initial Commercial Market Development. The cost of the Technology Development and Verification, and the Engineering and Design portions of the program will be borne by the government, EPRI and UTC while the development of the Initial Commercial Market will be the responsibility of UTC and the ultimate users, the electric utilities.

The plan is to build upon the current UTC 4.8 MW utility power plant technology which is similar to that used in the on-site program but operated at 50 psi for greater efficiency and evolve a design which has the efficiency and manufacturing cost characteristics needed to attain prototype development status. These include an 8300 BTU/kWh heat rate. To attain these goals technology development will be required on several of the power plant subsystems, however, the pacing technology development will be that done on the cell and stack. The main aspects of this work will involve increasing the operating pressure and temperature from the 4.8 MW level of 50 psi and 375° F to 150 psia, 405° F and to increase the cell planar area from the 4.8 MW size of 3.7 ft² to 10 ft², while keeping the 40,000 h life goal intact.

The plan philosophy with respect to fuel is that the power plant must be designed to operate on available fuels which, in the near term, will continue to be naphtha and natural gas. In addition, however, the power plant must have the capability to handle the simpler coal-derived fuels (CDFs) such as medium BTU gas.

In the Technology Development and Verification Testing phase of the program, evolutionary development is well underway on the basic integral ribbed substrate cell, the objective being to improve cell performance and endurance at 120 psia, 405° F. This activity has been focused on materials work and cell component technology for the 3.7 ft² cell size followed by verification testing in 20-cell, short stacks.

At 120 psia, 405° F, and 232 ASF, 2" x 2" subscale cells have achieved an initial performance increase of up to 100 mV compared to older type cells operating at 50 psia, 375° F, and 232 ASF. However, as expected, the higher temperatures and, to a lesser extent, pressures also cause an acceleration in the decay rates. In the UTC power plant system, increasing pressure without increasing temperature is not possible because of the interdependence of cell coolant and reformer conditions. Progress has been made

at reducing the sharp cell performance decay rate occurring during high temperature and pressure operation. The initial, rapid rate of decay has been reduced from 60 mV per 1000 hours to approximately 12 mV per 1000 hours, which is the 4.8 MW decay rate at 50 psia (see Fig. 4). The development associated with maintaining this low decay rate for very long times is now in process. This effort is in the stage at which the basic high temperature and pressure technology has been established and is in the process of being fine-tuned to provide the required endurance. Some progress toward this goal has been achieved.

Recently, 2" x 2" subscale cells have been successfully tested at 120 psia and 405° F for periods of up to 5000 hours at performance levels 125 mV higher than the performance projected for the 4.8 MW, 50 psi and 375° F power plant. Also, 20-cell, 3.7 ft² stack tests have attained these same high performance levels for periods up to 1500 hours. Both the 2" x 2" cells and the 20-cell stacks have matched the 4.8 MW performance decay projection of 12 mV/1000 hours over the periods tested.

The higher pressure/temperature performance capabilities that will be achieved in subscale 3.7 sq ft cells must be scaled up to 10 sq ft to achieve the cost reduction benefits of large area cells. To accomplish this, low cost fabrication development will be conducted on large area cell components in conjunction with the traditional materials work/cell technology development/verification testing addressed to the large area configuration.

Several other power plant subsystems will require development to evolve viable designs for the ancillary systems of a high pressure and temperature fuel cell. The subsystems requiring development are the thermal control heat exchangers, supervisory control system, and the fuel processing system. In the thermal control system, "contact cooling" will be developed to replace the costly formed plate condensers of the 4.8 MW power plant. The supervisory control system requires redesign and reoptimization for the new power plant operating conditions and the steam reformer of the fuel processor system must be reconfigured into an 11 MW unit.

The Technology Development and Verification portion of the program will culminate with the complete verification of all the power plant components on the basis of life, performance and cost. In the same time frame the Engineering and Design effort, which was initiated in parallel with the Technology Development phase, will have evolved a preliminary power plant specification and preliminary design. With this plus the results of the Technology Development effort, the power plant design and specifications can be finalized, and the users and UTC can undertake the Market Development portion of the program.

In the Market Development phase, activities will be conducted which are needed prior to making the first offering and the delivery of the first limited production power plants. The activities conducted by the manufacturer and utilities include preparation of accurate production cost estimates, assessment of the market for the initial fuel cells, preparation of the manufacturing facilities, and determination of pricing policies.

WESTINGHOUSE/ERC ELECTRIC UTILITY PROGRAM

The Westinghouse electric utility program evolved from a joint Westinghouse/Energy Research Corporation (ERC) program to develop on-site power plants. In this program ERC developed the basic electrochemical components and did the basic research required to design a steam reformer for natural gas. Westinghouse provided engineering and design for the total energy system and was to have provided the manufacturing capability. The on-site program had to be dropped by DOE due to funding constraints, but all of ERC's technology and much of Westinghouse's preliminary design work has been used as the basis for the electric utility power plant.

Stack Cooling

Probably the most important innovation of the ERC technology program is the gas cooling method. One of these, the DIGAS method distributes process air to both the cathodes (via bipolar plates) and to special cooling plates. The total amount of air that is required for reaction plus that required for cooling is supplied to the air inlet manifold. The air then flows through the cell via both the cathode flow (cathodic) channels of the bipolar plate and the channels of a special cooling plate. All of the air is collected in a common exit manifold and flows to an external loop where heat is removed, some of the oxygen depleted air is purged, and fresh air is added such that steady operation is maintained.

Since the cathodic channels of the bipolar plates and the cooling plate channels are parallel paths for air, the flow split is determined by the relative cross-sectional area, that is, relative resistance, of the cathode and cooling channels. A typical design is a 10:1 split with three times the stoichiometrically required amount (3 stoichs) of cathode air going to the cells and 30 stoichs of air going to the cooling plates.

Table I displays ERC's comparison of DIGAS and separate gas cooling to the two other commonly accepted cooling methods, process gas cooling and liquid cooling, performed under contract to DOE. The estimates are based on selected configurations of the three cooling methods. No effort was made to optimize any of them, however, all systems are reasonable and are consistent for comparison purposes. For any system chosen by a particular manufacturer, some optimization of the values presented in Table I may be expected. Each of the system's features will now be discussed.

Construction Simplicity

DIGAS cooling is relatively simple. Depending on stack operating conditions, at regular intervals a cooling plate is added to the stack of cells in the same manner as a bipolar plate is stacked. No special manifolding, connections or seals are required.

Process gas cooling is the simplest of all. There are no special cooling plates or stacking procedures needed. Several times the stoichiometric requirement of cool air is supplied to the stack. All the air flows through the cathodic channels of the bipolar plate. Upon exiting the stack, the air can be vented or recycled as in the DIGAS method.

Separate gas cooling (see Fig. 5), the alternate to DIGAS, keeps the cathodic reactant air separate from the cooling system gas (air, helium, etc.). This improves electrical performance due to higher O_2 concentration of the cathode as well as reducing the need for acid resistant heat exchangers in the cooling stream. Separate gas cooling using air has been selected for the Westinghouse programs.

Liquid cooling is by far the most complex and expensive. It involves passing a liquid coolant through special cooling plates inserted at regular intervals in the stack. The coolant may remain in the liquid phase at all times using only its sensible heat to cool the stack, or the coolant may partially vaporize, putting pressure on the system, using latent heat for part of the cooling load. The coolant must be either separately manifolded, or supply lines must be connected to each individual cooling plate. Standard heat transfer materials, such as copper or aluminum, are corroded by phosphoric acid, and must be protected if they are to be used. Standard, inexpensive fuel cell materials such as graphite or graphite/resin composites present difficulties in sealing and making connections. Finally, the liquid itself and coolant lines, if electrically conductive, provide a possible shorting path in the cell (shunt currents result in parasitic losses). In the UTC two-phase water cooling method, water treatment to reduce electrical conductivity is required.

Electrolyte Loss

Since the vapor pressure of phosphoric acid (hence electrolyte loss) is a weak function of temperature, the main consideration here is the amount of gas flowing past the electrodes to carry off electrolyte. In both gas and liquid cooling methods, a small excess of reactants flow past the electrodes, while in a process gas cooled stack all the cooling air must pass the electrodes. Process gas cooling has the highest electrolyte loss which translates into the shortest life or the shortest time between electrolyte replenishment. No contractors plan to use process gas cooling.

Reliability

For gas cooling, reliability is high since there is no special cooling fluid and no complex manifolding or connections. Most air leaks probably can be ignored. A leak in a liquid cooling system could cause a shutdown to allow for repair or replacement of the defective cooling plate. In addition, the gas pressure is low compared to the two-phase liquid system used by UTC.

External Heat Exchange

Heat recovery is by far best with a liquid or two-phase liquid cooling system. Systems studies have indicated that satisfactory heat recovery is attainable with either of the recirculating air cooling systems.

Cost Comparison

This is an estimate based on materials used and construction complexity. It reflects the materials and construction problems of liquid cooling.

Total Differential Temperature

This concerns temperature gradients across a fuel cell stack. The total temperature differential, ΔT , between any two points in the stack contains two components, a ΔT in the stack direction (perpendicular to both reactant flows) and a ΔT in the coolant flow direction (parallel to one reactant flow). It is important to maintain the stack temperature within a fairly narrow band. If the temperature drops too low, CO poisoning of the anode catalyst becomes a problem, and, if the temperature is too high, the operating limit of the stack materials is exceeded. A commonly accepted operating range is between 350° and 400° F. Since every cell is cooled equally in the process gas method, there is no stacking direction component of the total ΔT . Also, since the coolant directly contacts every cell and its temperature and flow rate cannot be independently controlled, the inlet area is cooled more than in other methods. This accounts for the large ΔT in the flow direction. For both the gas and liquid cooling methods, the same number of cells between cooling plates is assumed. This sets the stacking direction ΔT at 15° F for both systems. The difference in flow direction ΔT results from the differences in liquid and gas heat transfer characteristics.

Total Auxiliary Power

These requirements are mainly a function of the amount of coolant circulated and the cross-sectional area of the coolant passages. As expected, the power requirements for pumping a liquid coolant is quite small. Since all the cooling air flows through the cathodic channels of the bipolar plate, the power requirement is quite large for the process gas method.

Pressure Drop Across Cell

This is a function of the air flow through the cathodic channels of the bipolar plate. The same amount of cathode air is required for both gas and liquid cooling, hence the same pressure drop. The high pressure drop for process gas cooling reflects the high air flow rate required to satisfy both the cathode fuel cell reaction and the necessary cooling.

Based on the above considerations, ERC has concluded that the gas cooling concept offers the best compromise between reliability, life-cycle cost, and heat recovery.

Power requirements for DIGAS are less than that for process gas since a large fraction of the total air flows through large area cooling channels. Separated gas could have a lower power requirement since the process air and cooling can be independently controlled.

Westinghouse has recently made a more detailed study of gas cooling. Under DOE contract they developed a lumped parameter fuel cell stack simulation code that calculates reactant gas composition, current-voltage characteristics, and heat transfer characteristics for a gas-cooled fuel cell stack. In the model, the cell area is broken down to a grid of finite elements so that power and heat generation can be calculated as functions of temperature and reactant composition, as each varies from point to point in a cell.

As mentioned previously, one of the major drawbacks of gas-cooling is a higher total differential stack temperature than that of liquid cooling. Westinghouse has redesigned the gas-cooling plates in an effort to reduce the differential temperature. Results of the simulation show that a 20° F differential temperature can be achieved with proper design. This comes close to what can be achieved with liquid cooling.

Program Status

The Westinghouse program is at the point where most of the enabling electrochemical component technology has been developed. Presently, the electrochemical components are being optimized for cost and life; basic design and development are progressing for other power plant components, and an initial system design effort is complete. The most unique characteristic of the Westinghouse power plant is that one of the reactant gases, rather than a liquid, is used as the stack coolant. An EPRI-funded study showed DIGAS cooling to be a feasible method of power plant cooling, and that the power plant performance and cooling loop costs were satisfactory. However, Westinghouse will use the separate gas-cooling previously described. For electrolyte management, an acid replenishment system has been built into the fuel cell stack. This system will also accommodate acid volume changes due to differing operating conditions.

Westinghouse, like UTC, plans to operate the power plant at moderate pressure. The current year's work will center on two areas. The first will be to better define the power plant by developing a conceptual design, including trade-off studies, leading to a preliminary specification and a program requirements document. The other area of work, currently in process, is to evaluate the on-site fuel cell components, including cooling system, at the higher temperatures and pressures under consideration and to continue technology development as required.

ENGELHARD INDUSTRIES ON-SITE PROGRAM

Engelhard contracted with DOE in 1976 to study several fuel cell applications and to develop fuel cell stack technology. Their previous experience included building fuel cells for an Army lift truck development program, and building and marketing H₂/O₂ laboratory-size demonstration fuel cells. They also have an Army-funded fuel cell development contract. Engelhard has developed stack components, and has defined attractive applications for the OS/IES system conceptual design effort. The component development effort has resulted in several unique approaches to fuel cell design. One area of innovation is their bipolar plate, the device which

separates and directs the flow of reactants and provides electrical and thermal conduction between individual cells. The conventional bipolar plate is a single piece of conductive material with reactant flow channels either molded or machined into either side. Engelhard's approach is to split the bipolar plate into three sections, an impervious center section for reactant separation, with an open cell foam section, with or without channels, on either side (for reactant flow). All sections are made from organic precursors that are graphitized, then densified. This process is very compatible with mass production and promises considerable cost savings over one-piece, bipolar plates, which must be individually molded or machined. Engelhard has also developed a low cost cooling plate that can be made of conventional materials and fabricated using conventional furnace brazing techniques. The coolant is a dielectric liquid. This cooler offers potential cost reduction over other liquid and ebullient liquid coolers. A complete 5 kW power plant, incorporating a methanol reformer and a utility grid compatible power processor, has been built and tested. Acid management capability that can accommodate volume changes during transients, as well as acid addition as needed, has been incorporated.

The unique features of the Engelhard OS/IES effort currently are in the following areas: (1) development of a fuel conditioner that will operate on methanol (methyl fuel); (2) novel bipolar plate approaches; (3) liquid intercell cooling; and (4) matrix and electrolyte transport reservoir technology. In the current two-year contract the electrocatalysis task is solely funded by Engelhard. Therefore, the details of any unique electrocatalyst developments are proprietary.

Fuel Processing

Methanol will be initially used in the Engelhard OS/IES. (The fuel chosen for the UTC OS/IES program was natural gas.) Methanol selection was based upon its projected availability from coal in the 1990 time frame. A 5 kW methanol fuel processor has been constructed.

Bipolar Plates

In the stack area, two novel bipolar approaches appear promising. Under subcontract, Pfizer is developing chemically resistant carbon (vitreous carbon and/or graphite) structures starting with reticulated vitreous carbons or cloths. One of these structures, the so-called B element, is impermeable to gas transport and will serve as the bipolar separator plate connecting two adjacent cells. See Fig. 6. (In the UTC ribbed substrate integral cell concept, this is UTC's separator plate.) The other structure, the so-called A element, is porous to permit fuel or oxidizer transport to the electrochemically active electrode areas (which could be on the A elements). Graphite structures, using Pfizer's chemical vapor deposition techniques, are being utilized to help produce the required properties in both A and B elements. The resulting bipolar plate consists of a B element sandwiched between two A elements. In addition, electrolyte storage can be accommodated in the A element.

In the second approach, thin graphite plates are separated by a gas-impermeable layer of a chemically resistant material (such as graphite) that permits satisfactory electrical and thermal conductivity. Grooves in each plate will permit reactant transport. If the graphite plates are porous and connected suitably to the matrix, they can provide an electrolyte reservoir for matrix replenishment or for overflow volumes resulting from changing conditions (volume tolerance). Several promising material combinations are under test. The Engelhard bipolar plate approach has some aspects in common with the UTC ribbed substrate integral cell approaches previously discussed.

Intercell Cooling

A brief discussion of the liquid intercell cooling approach employing a dielectric fluid, the Engelhard method, was presented previously in connection with the Westinghouse/ERC cooling approach. The Engelhard design makes use of baffles to provide good heat transfer control yet is designed for ease of fabrication. The protection of the aluminum cooler, so it will hold up for the five year stack life goal under the corrosive acid environment of the fuel cell stack, is believed to be solved with suitable seals. A second (back-up) design being developed incorporates a chemically resistant fluid transport member.

Matrix

The matrix effort emphasizes materials capable of operating at temperatures up to 400° F, and construction that results in good electrical and thermal conductivity, good transport (flow) properties, and satisfactory reactant crossover resistance. A thin SiC-fluorocarbon matrix that incorporates good electrolyte transport is laminated to each electrode.

Electrolyte Management

An acid replenishment system has been built into the stack. Acid volume changes are also handled by this system.

ADVANCED RESEARCH AND TECHNOLOGY

The current focus is on improving the air electrode (cathode) specifically with its supported platinum or platinum alloy oxygen-reduction catalyst, where most of the fuel cell's inefficiency lies. Improved catalysis will result in lower capital costs, lower operating costs, or a combination thereof, by balancing higher efficiency, higher power density, lower operating temperatures (longer life) and catalyst costs. Lower temperature operation could be desirable in order to lower materials costs and to increase cell life. Another goal is to find a suitable, less expensive replacement for the platinum (Pt) catalyst material.

In 1981, DOE-sponsored research has been concerned with:

1. Developing a more stable supported cathode catalyst.
2. Developing a more active supported platinum-based cathode catalyst.

3. Developing a more active and more impurity-resistant anode catalyst.
4. Developing a new non-platinum cathode catalyst.
5. Determining the effects of anode impurities.
6. Investigating accelerated aging tests and short term means of determining long term stability.
7. Evaluating novel electrolytes.

Most of this research is being conducted either by small private companies, or at government or national laboratories. In addition, in the complementary EPRI-sponsored program alternate acid electrolytes are under investigation.

CONCLUDING REMARKS

As part of the nation's energy program, three major contractor or contractor teams (UTC, Westinghouse/ERC, and Engelhard), active in the terrestrial phosphoric acid fuel cell field, are receiving government support to develop commercial fuel cell power plant systems. Both UTC and W/ERC are working toward commercializing fuel cell power plants for electric utility applications. UTC and Engelhard are addressing the OS/IES program.

While similar in many respects, significant technological and system differences exist among the three contractors. These include intercell cooling, bipolar/separator plate, electrolyte management, materials of construction, fuel selection, and system design philosophy. Phosphoric acid fuel cell technology/development efforts for both the electric utility and OS/IES applications are directed toward reducing cost and increasing reliability. The longstanding barrier to the attainment of these goals, which manifests itself in a number of ways, has been materials.

In addition, for the electric utility application, UTC and Westinghouse are pursuing higher temperature and pressure operation. The initial performance gains due to higher temperature and pressure must be balanced against possible shorter life as well as the cost and performance implications upon the balance of the system.

TABLE I. - COMPARISON OF COOLING SCHEMES FOR PHOSPHORIC ACID FUEL CELL SYSTEM

	DIGAS or separate gas cooling	Process-gas cooling	Liquid cooling
1. Construction simplicity	Simple	Simple	Complex
2. Electrolyte loss	Low	High	Low
3. Reliability	High	High	Low
4. External heat exchange	Fair	Fair	Good
5. Cost of cooling subsystem, % stack cost	5	5	25-50
6. Total differential temp. °F	20	60	20
T _{cell} in stacking direction °F	10	0	15
T _{cell} in flow direction °F	10	60	5
7. Total auxiliary power req't., %	2	5	1
Stack auxiliary power req't., %	0.5	3	0.5
Balance of system auxiliary power req't., %	1.5	2	.5
8. Pressure drop across cell, in. H ₂ O	.4	3.5	.4

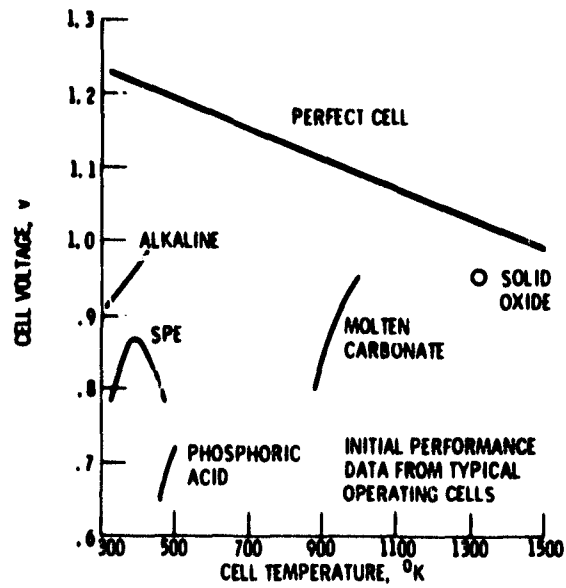


Figure 1. - Effect of temperature of fuel cell voltage.

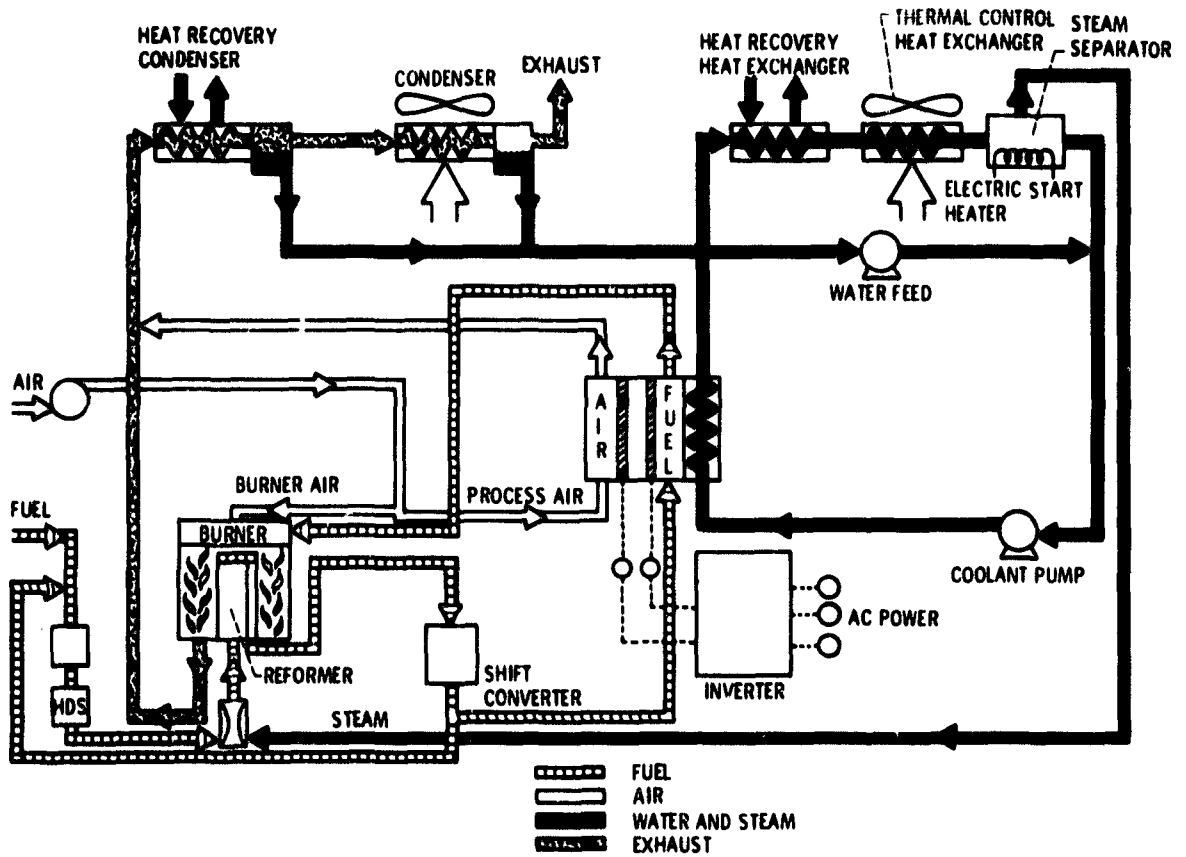


Figure 2. - 40-kW power plant system.

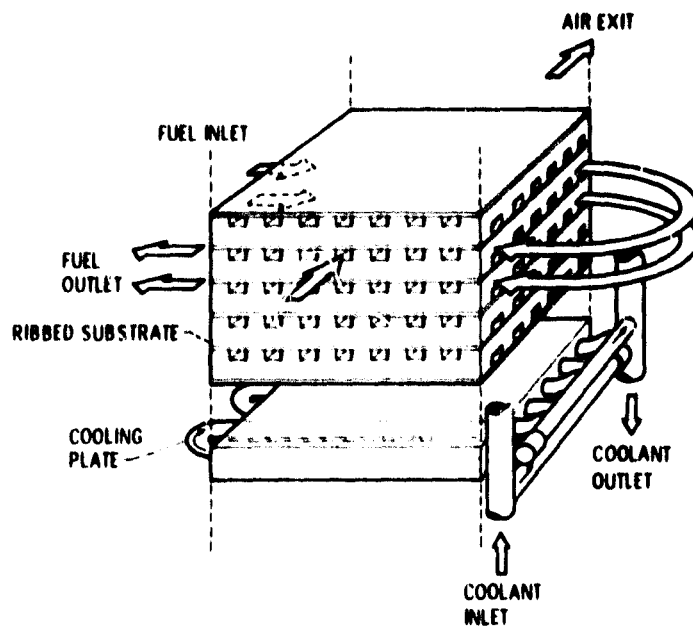


Figure 3 - UTC phosphoric acid fuel cell structure.

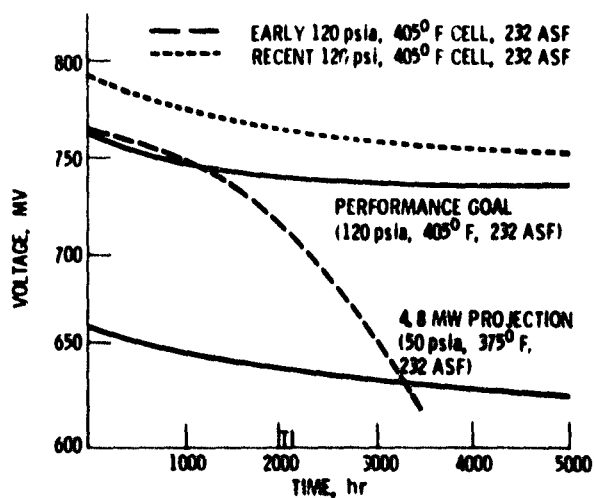


Figure 4 - Improvement in high temperature and pressure cell performance stability.

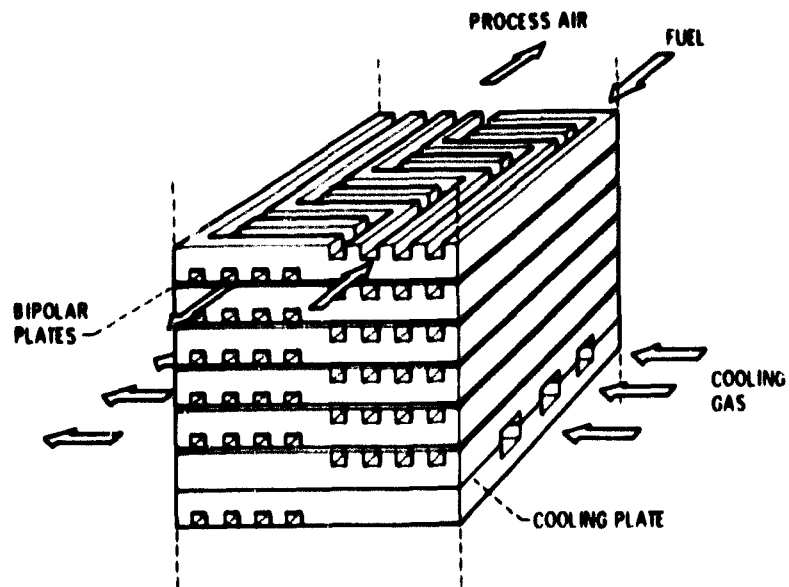


Figure 5. - Separate gas cooling.

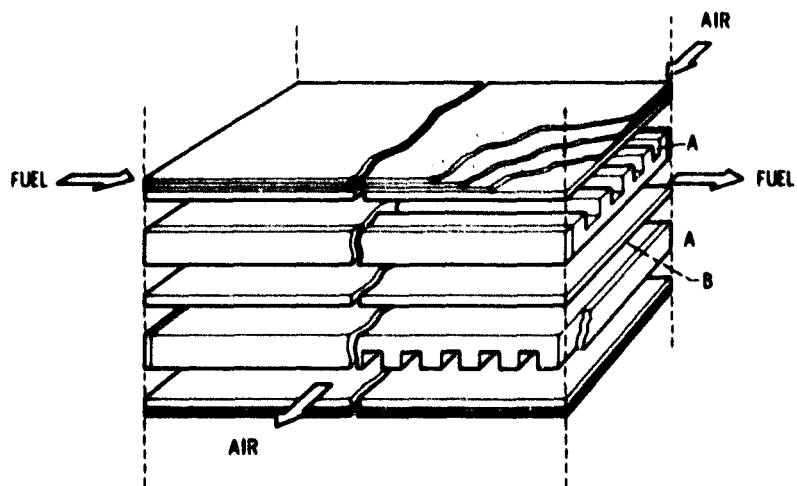


Figure 6. - A-B-A bipolar plate construction.